THESIS

ERGONOMIC EVALUATION OF TWO ALTERNATIVE HANDLES FOR SHOVELS AND RAKES DESIGNED TO PREVENT LOW BACK PAIN

Submitted to

The Engineering Honors Committee

119 Hitchcock Hall

College of Engineering

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by

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ABSTRACT

Two handle attachments that are designed to decrease the bending and twisting encountered while shoveling and raking have become commercially available: the BackSaver Grip and the Backsaving Handle™. This study aimed to investigate the effects that the two aids have on the lower back in these activities. Fourteen subjects performed raking and shoveling tasks. MotionMonitor™ (Innovative Sports Training, Inc.) hardware and software, and force-plates were employed to record the continuous motion of subjects performing these tasks. Lateral bending, flexion, and twisting angular displacements and moments were calculated for each subject. The effects of the aids were evaluated using SAS software (SAS Institute, Inc.). The study found that both handles significantly reduce twisting moment, twist angle, and flexion angle during the shoveling task. When using the handles during raking task, only flexion was significantly reduced. In conclusion, the products present a possible way to decrease the risk factors associated with raking and shoveling.

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1. INTRODUCTION

Low back pain is a common complaint for many people at some point in their life, with 15-45% of adults suffering from low back pain annually (Frymoyer, 1997). Causes of low back pain are varied and difficult to assign, but researchers have been able to pinpoint many risk factors, such as bent and twisted postures, load moments, and trunk lateral and twisting velocities (Punnett et al, 1991; Marras et al, 1995). These risk factors can be found in a variety of manual tasks, such as shoveling.

Shoveling has been well studied, beginning with work on shoveling productivity and since then the productivity and efficiency of shoveling of various materials has been well documented (Frievalds 1986a). Frievalds considered the ergonomic effects of shovel design and shoveling and devised a list of recommendations, such as suggested lift angle and blade shape, for different shoveling tasks (1986b). Since then more work has been done on handle design. One study looked at a bent-shaft design and found that this design decreased trunk flexion while shoveling (McGorry et al., 2003). Another design tested was a shovel with an additional handle attached to the socket of the shovel, and the findings were varied, due to usability issues, but it was determined that the additional handle did decrease bending in users (Frievalds, 1986b; Bridger et al., 1998). Raking, on

the other hand, has not been extensively studied.

In this study, two products that seek to prevent low back pain by reducing the amount of bending and twisting are the BackSaver Grip and the Backsaving Handle™. Both of these handles attach to the center of the shaft rather than at the socket, as opposed to the handles evaluated in other studies. This study aimed to assess the BackSaver Grip and the Backsaving Handle™ in their ergonomic capability. Both the BackSaver Grip and the Backsaving Handle™ are products that attach to long-handled tools, such as garden rakes, leaf rakes, mops, and shovels. These handles facilitate an improved posture while using long-handled tools by re-orienting the position of the lower hand such that bending and twisting is reduced. The handles' application in shoveling and raking was investigated in this study.

The objectives of this study were to determine the bending (lateral and forward flexion) and twisting angles and moments about the lower back for each handle attachment and the control condition (no attachment) during a shoveling task and a raking task and determine whether subject anthropometrics impact the results. It was hypothesized that both handles would significantly decrease the bending and twisting angular displacements and moments about the lower back when shoveling and when raking.

2. METHODS

2.1 Experimental Design

Both portions of the study had a repeated measures design, which decreases the chances of differences in raking and shoveling styles between participants. In this design, the independent variable was the handle for which there were three conditions comprised of the two different add-on handles and a control (no handle) condition. The dependent variables were the flexion, lateral bending, and twist angles and the flexion, lateral bending, and twist moments. The amount of force required was controlled by keeping the weight lifted by the shovel constant for each trial. The weight for shoveling was set to five percent of the subject's body weight. Similarly, in the raking study, the pulling force remained constant for each trial at four percent of the subject's body weight.

2.2 Subject

For the study, fourteen subjects were tested, seven male and seven female. To be a subject, one must have been between the ages of eighteen and forty at the time of participation, in good health, and have no prior back problems. Subjects were recruited from the Ohio State campus population. The subjects ranged in age from twenty-one to twenty-five. The average height of the subjects was 175 cm (range 157 to 185 cm). The average weight of the subjects was 76 kg, (range 56 to 104 kg). More detailed information on the subjects can be seen in Table 1.

2.3 Measurement/Instrumentation

The two handles added to the tools were the BackSaver Grip and the Backsaving Handle™. The two handles differ in their design, and the BackSaver Grip is made of

plastic, while the BackSaving Handle™ is made from aluminum. A common placement of each handle on each tool was used for each subject. Figure 1 shows the two handles and where they were placed on the tools.

For the raking trials, a garden rake was attached to the weight using two pulleys, one attached to the ground and the other attached to the ceiling. The weight was suspended from the ceiling to keep the force constant. A force scale was used to indicate when the subject had started pulling.

For the shoveling trials, the participants used a snow shovel to scoop, lift, and dispose a weight from one area to another. A force scale was used to indicate when the subject had lifted the weight, and another force scale was used to indicate when the subject had disposed the weight.

Kinematic data were obtained using electromagnetic sensors (Accension™) attached at the sacrum, right shank, left shank, right thigh, left thigh, right arm, left arm, thorax, and head using Velcro straps. The subjects stood on two force plates, which measured the ground reaction forces under each foot. All data was acquired by the computer and read by The MotionMonitor™ (Innovative Sports Training, Inc.) software, which recorded the subjects' movements and calculated bending and twisting angles and spinal moments at 120 Hz.

2.4 Detailed Study Procedures

Upon entering the Orthopaedic Ergonomics Laboratory the procedure was described and each subject was presented with an informed consent document. Anthropometric data including height, shoulder height, elbow height, index finger height, hip width, knee width, ankle breadth, and the shoulder breadth were obtained. The

subject was instrumented with the electromagnetic sensors and instructed to stand on the two force plates, one foot on each, for the duration of the study.

The sequence of raking and shoveling was counterbalanced by changing the order of which was done first by each subject in order to decrease learning effects and fatigue. For each subject, the sequence of the handle conditions was be randomized, and for each condition, there was eight trials. Between raking and shoveling, the subjects were given a break that lasted about five minutes.

For the raking portion, the subjects were instructed to pull the rake from a starting point to another ending point (See figure 2). Once the subjects had pulled the rake to the ending point, the investigator took the weight that the subject had lifted from the force scale and set it back on the force scale while the subject set the rake in the original position. This allowed the rake to be returned to the starting point without additional load. Subjects were allowed to choose a comfortable location to place their feet anywhere on each respective force plate, but were instructed to keep their feet in their original positions on the force plates for each set of trials. Each subject was allowed to practice the motion as many times as needed to feel comfortable with the motion. Once the subject felt comfortable, he/she repeated the motion eight times in succession and the data were recorded by the computer. This was done for each handle condition. The subjects received break lasting about one minute between each handle condition.

For the shoveling portion, the subjects were instructed to use the snow shovel to lift a weight off the force scale and turn and toss the weight onto the other force scale. Once the weight was on the second force scale, the investigator replaced the weight on its original position on the first force scale. Subjects were allowed to choose a comfortable

location to place their feet anywhere on each respective force plate, but were instructed to keep their feet in their original positions on the force plates for each trial. See figure 3 for the set-up. The subjects did this eight times for each handle condition. Between each handle condition, the subjects were given a break lasting about one minute and also had a short break between each trial to allow the researcher to replace the weight on the first force scale.

After the trials were completed, the subject was asked to stand in a normal position, and the computer recorded the subject's angles and moments. This provided baseline data for the statistical analysis.

2.5 Statistical Analysis

For the analysis, only the last five trials for each handle condition and tool were used to ensure that the subject had found a comfortable pattern of motion for each handle condition and tool. The maximum and minimum of the flexion, lateral bending, and twist angles and flexion, lateral bending, and twisting moments were recorded for each trial. Then the baseline data was subtracted off the maximums and minimums. For the lateral bending and twisting motions and moments from each trial, the absolute value of whichever peak, the maximum and minimum, was larger was selected for analysis. These peak values were averaged across the five trails defining a single handle condition for each subject.

The remaining data was prepared as an input for SAS software (SAS Institute Inc.). The data was analyzed using the GLM procedure and the Ryan-Einot-Gabriel-Welsch Multiple Range Test for each angle and moment for both tools. An alpha level of 0.05 was used.

3. RESULTS

3.1 Shoveling Results

ANOVA analysis of the shoveling data showed that both handles significantly decreased the flexion angle, twist angle, and twisting moment of the lower back compared to the control. This can be seen in Table 2 and figures 4 and 5.The lateral bending angle, flexion moment, and lateral bending moment were not significantly changed with the use of either handle. Post-hoc tests showed that both handles had similar effects when shoveling.

The effects of arm length were also investigated. The subjects were divided into two groups based on arm length for analysis. Analysis showed that neither handle attachment had a significant effect on the short arm group, but the handles were close to making a significant change ($p = 0.0568$) for twist angle. In the analysis of subjects with longer arms, the handles showed a significant decrease in the flexion and twist angles and the twist moment. The handles did not significantly affect the lateral bending angle and the flexion and lateral bending moments.

3.2 Raking Results

Due to limitations in the data only 4 subjects could be analyzed for the raking task. The analysis showed that while raking with the additional handles, only the flexion angle had a significant change from raking with no additional handle (Table 2). The lateral bending moment was close to having a significant change ($p = 0.0655$). When raking with the additional handles, there were no significant changes in the lateral

bending angle, twist angle, flexion moment, and twisting moment. This can be seen in figures 6 and 7. Both handles had similar effects when raking.

4. DISCUSSION

4.1 Shoveling

The data shows that both additional handles could aid in preventing low back pain by decreasing twist and flexion angles and twisting moment. These factors have been shown to affect the risk of developing lower back pain and musculoskeletal disorders (Punnett et al, 1991; Marras et al, 1995). The data do not show that either handle will significantly decrease the lateral bending angle, the flexion moment, and the lateral bending moment and may not prevent low back pain due to these factors. These findings correspond with other similar studies done on shovel and spade design results. One study on another two-handled spade concluded that the additional handle could reduce the risk of back injury (Bridger et al, 1998). The study on the bent shaft design found that using the new design significantly decreased trunk flexion (McGorry et al, 2003). The results of this study, along with the other studies, further verify the possible positive effects of using modified shovels.

Arm length was also an important factor when using the handles. When stratified by arm length, subjects with shorter arms do not appear to gain the same benefits as those with longer arms. This may be affected by using a common placement for all subjects. Perhaps if the handles would have been adjusted for each individual subject, these results may be the same. Overall, both handles had similar effects; therefore, if a handle were employed, the choice of handle may be based on other factors such as personal preference.

4.2 Raking

From the data, it is seen that the additional handles significantly decrease flexion angle and could possibly decrease the lateral bending moment. These factors have been shown to impact the risk of low back pain (Punnett et al, 1991; Marras et al, 1995). A majority of the data from the raking study was found to be unreliable due to problems with The MotionMonitor™ software. Only data from four subjects were found to be reliable. Yet, since significance was found for one factor, it is reasonable to suggest that the roles of the handles while raking should be further studied. From the data, both handles had similar effects when raking, and if a handle were employed, the choice should be based on other factors, such as personal preference, because one handle was not shown to be better than the other.

4.3 Limitations

There are several limitations to the study. Results may differ if the subjects were allowed to move their feet during the trial; subjects could have moved their feet instead of bending or twisting to finish the motion. Also, the weight was kept constant, whereas in many practical applications, the weight could vary, and this could affect the outcome. In addition, while shoveling was investigated, other common tasks with a shovel, such as digging, were not studied. Therefore, the effects of using the handles are only applicable to the specific scenario tested.

4.4 Further Research

One topic for further research would be to analyze the handles over a variety of tasks, such as mopping rather than only shoveling and raking. Another potential idea for research would be to develop a better design for an add-on handle, such as a handle that's

position is easily adjustable along the axis of the shaft and about the shaft. Both handles significantly decreased some of the variables shown to be risk factors for low back pain but not all. Research into designing a product that decreased more of the risk factors could result in improved safety. An additional suggestion for further study would be finding the ideal placement on the tool for different tasks. Our experience shows that optimum handle placement may vary depending upon the shovel load and task, and user anthropometrics. Another possible area for research would be studying the effects of various attributes, such as age, height, etc. while using handle attachments. An additional topic for research could be the effect the handles have on productivity. Add-on handles open up many new possibilities for further research because of their range of uses.

5. CONCLUSION

Both handle attachments have been shown to decrease some of the factors associated with low back pain while shoveling. More research is suggested to develop attachments that further decrease risk factors for low back pain and injury, determine optimal placement and usage of the auxiliary handles, and to determine their interaction task and user attributes. Both handles produced similar results in both the shoveling and the raking tasks, thereby suggesting the choice of which handle to use during these tasks should be based on personal preference.

TABLES AND FIGURES

TABLE 1.

Anthropometric Data of Subjects.

Subject	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Gender	F	M	M	M	M	F	M	F	F	F	M	F	F	M
Age	20	21	22	22	22	21	25	20	22	21	22	20	20	21
Height	160.9	182.4	180.9	176.1	182.1	174.9	184.4	157	169.6	174.2	185.1	159.1	174.1	183.5
Weight	165	185	170	196	120	230	215	125	125	150	175	150	145	182
Shoulder Height	130.9	151.8	149.1	145.7	148.2	145.1	150.1	128.9	145	146.1	150.7	133.7	141	154.5
Elbow Height	103.1	118.6	117.5	116.4	119.3	115.5	117.9	102.1	112.3	114.1	120.7	105.8	110.6	118.2
Index Finger Height	65.8	74.4	72.9	69.7	74.6	72.1	71.3	63.2	67.4	68.2	76.1	66.8	70.4	70.9
Arm Length	65.1	77.4	76.2	76	73.6	73	78.8	65.7	77.6	77.9	74.6	66.9	70.6	83.6

TABLE 2.

Summary of Results

Tool	Dependent Variable	F Value	Degrees of Freedom	p-value
Shovel	Flexion Angle	6.19	2	0.0063
	Lateral Bending Angle	1.02	2	0.3748
	Twist Angle	10.06	2	0.0006
	Flexion Moment	0.06	2	0.9398
	Lateral Bending Moment	2.23	2	0.1275
	Twisting Moment	9.00	2	0.0011
Rake	Flexion Angle	18.36	2	0.0028
	Lateral Bending Angle	1.33	2	0.3319
	Twist Angle	1.8	2	0.2447
	Flexion Moment	0.18	2	0.8376
	Lateral Bending Moment	4.44	2	0.0655
	Twisting Moment	3.14	2	0.1166

Fig.1 Shovels with Handles Attached.

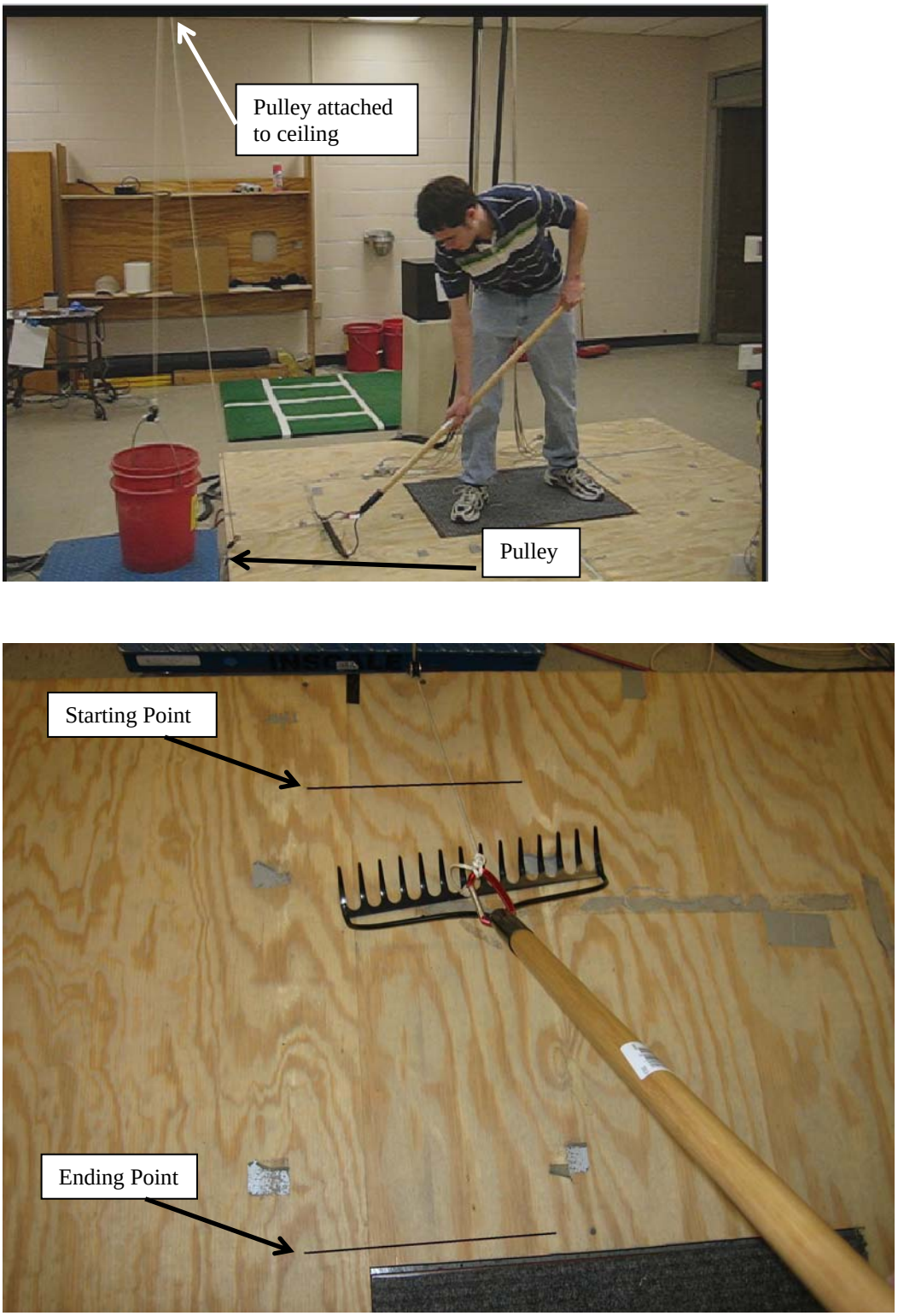

Fig. 2. Raking Apparatus

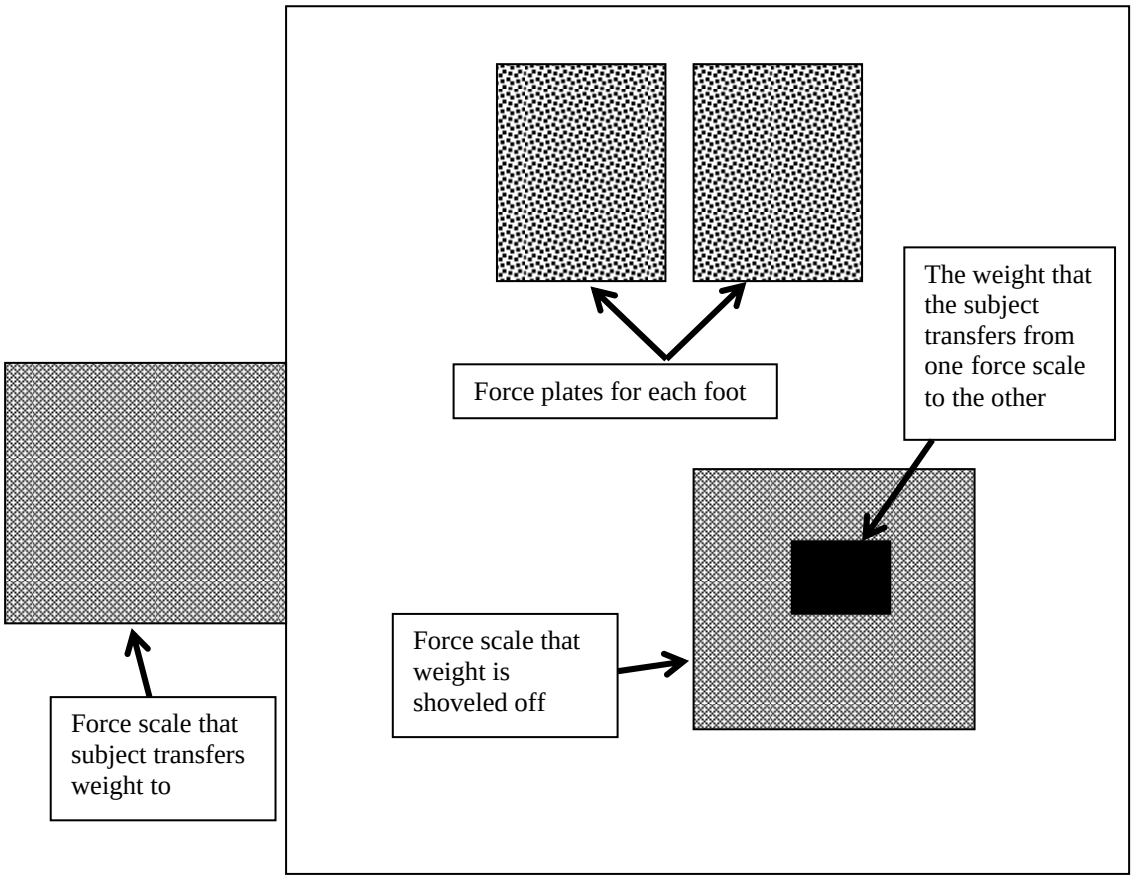

Fig. 3. Shoveling Apparatus

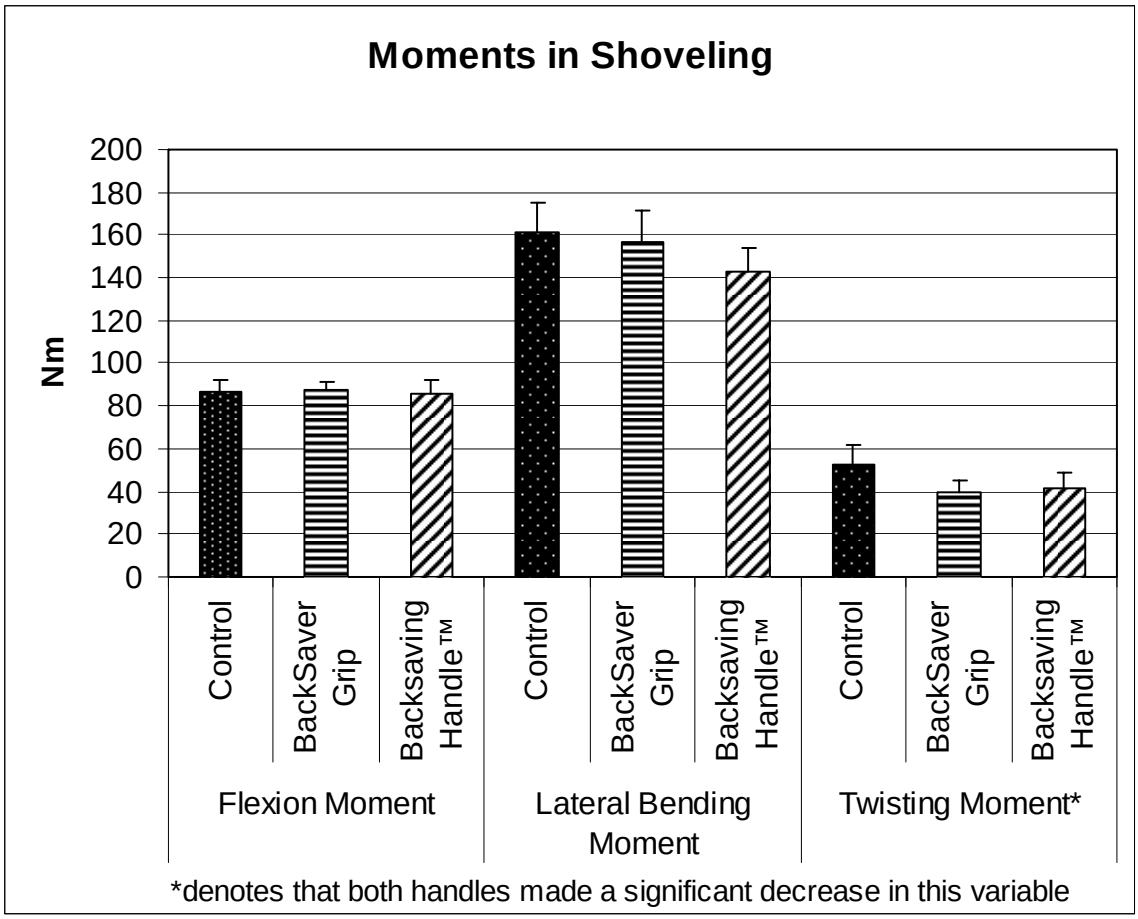

Fig. 4. Graph of the moments measured whilr shoveling.

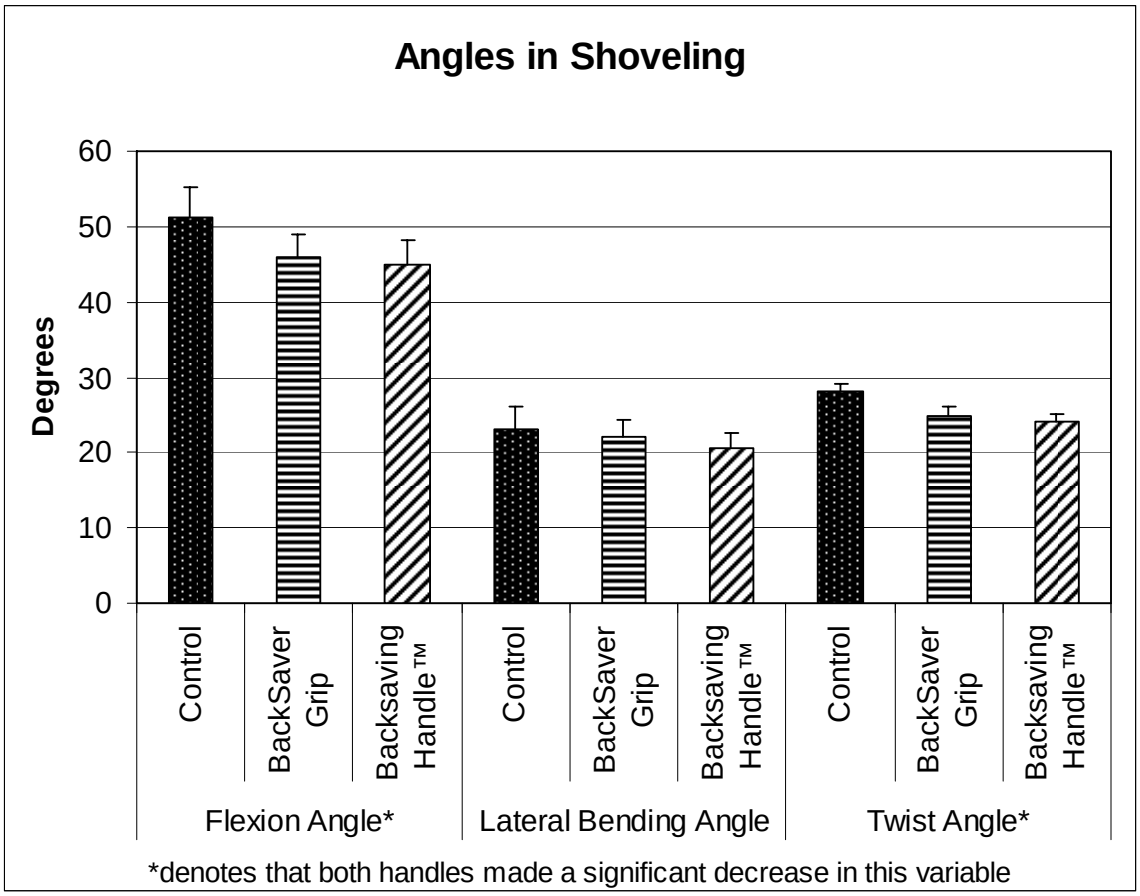

Fig. 5. Graph of the angles measured while shoveling.

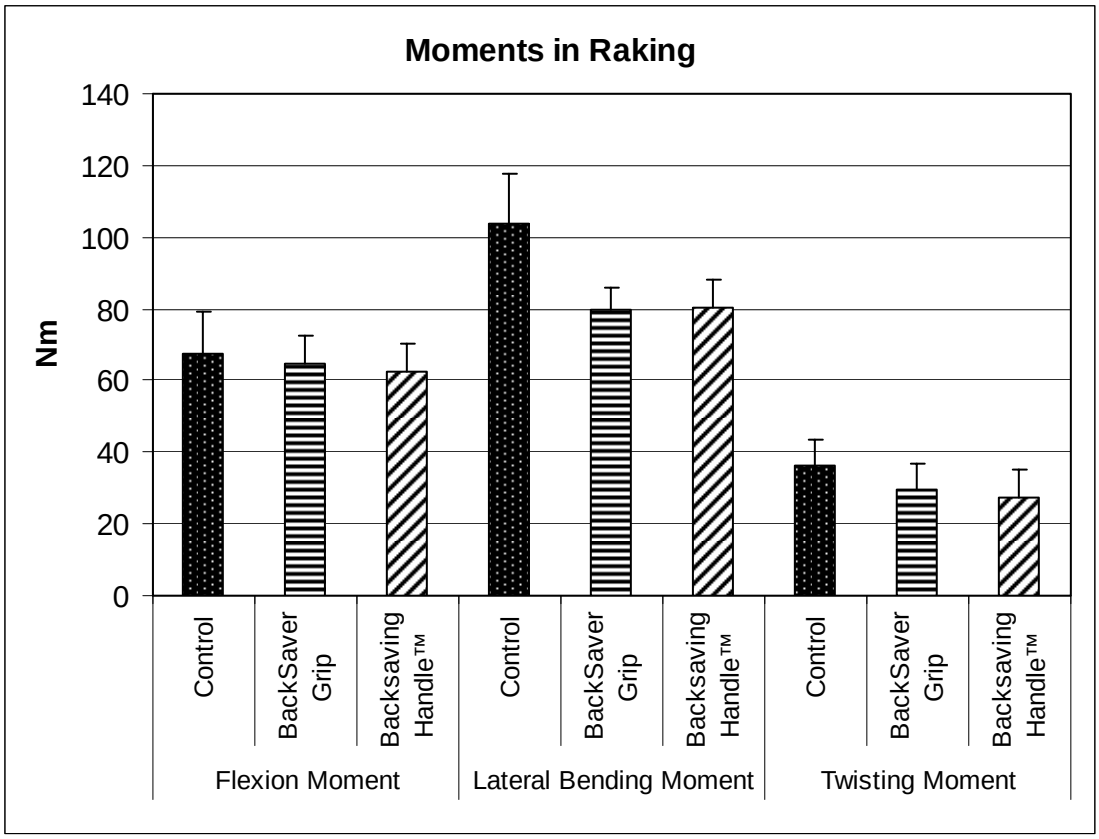

Fig. 6. Graph of the moments measured while raking.

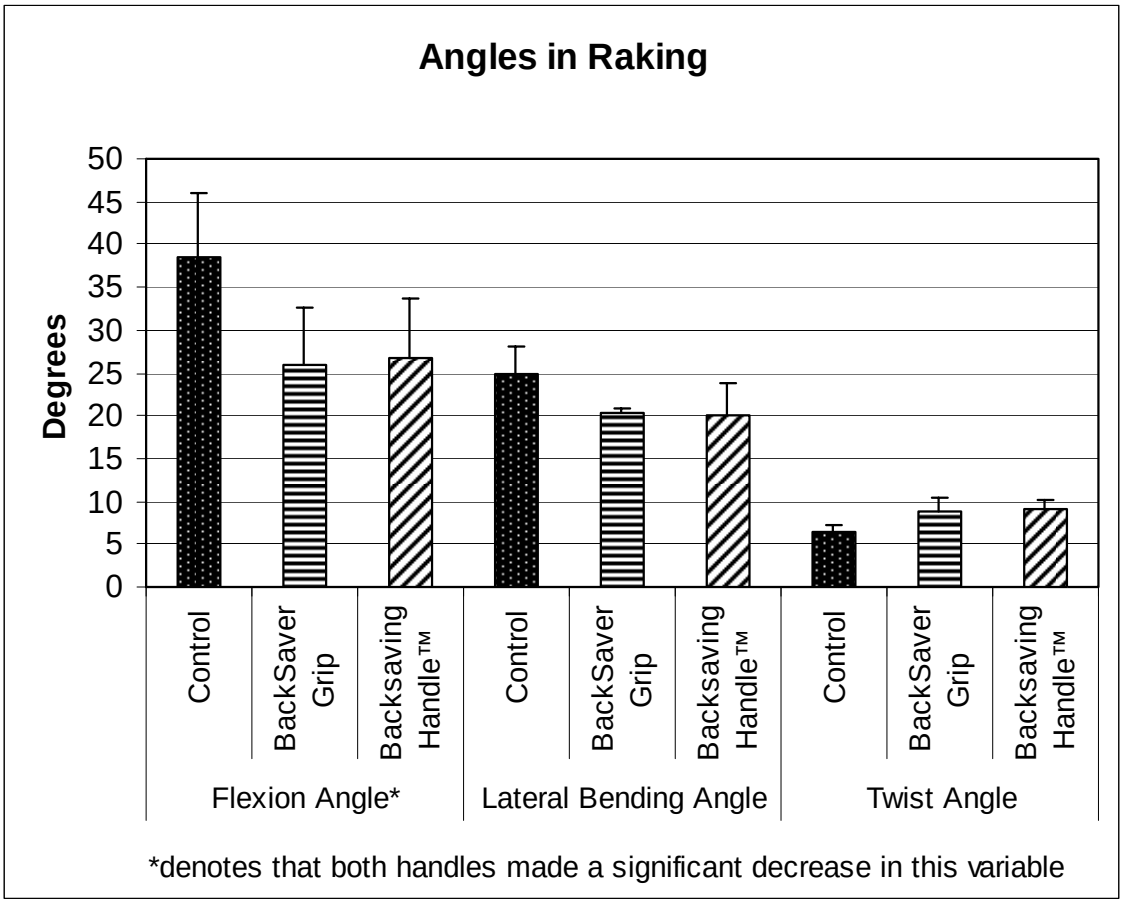

Fig. 7. Graph of the different angles measured while raking.

BIBLIOGRAPHY

Andersson, G.B.J., 1997. The Epidemiology of Spinal Disorders, in Frymoyer, J.W. (Ed.), The Adult Spine: Principles and Practice. Lippincott-Raven Publishers, Philadelphia, pp.93-141.

Bridger, R. S., Cabion, N., Goedecke, J., Rickard, S., Schabort, E., Westgarth-Taylor, C., Lambert, M.I., 1997. Physiological and subjective measures of workload when shovelling with a convention and two-handled ('levered') shovel. Ergonomics 40, 1212-1219.

Bridger, Robert S., Sparto, P., Marras, W.S., 1998. Spade Design, Lumbar Motion, Risk of Low-back Injury and Digging Posture. Occupational Ergonomics 1, 157-172.

Bridger, R.S, 2003. Introduction to Ergonomics, 2nd ed. Taylor and Francis, New York.

Frievalds, A., 1986a. The ergonomics of shoveling and shovel design – a review of the literature. Ergonomics 29, 3-18.

Frievalds, A., 1986b. The ergonomics of shoveling and shovel design – an experimental study. Ergonomics 29, 19-30.

Frievalds, A., Kim, Y.J., 1990. Blade size and weight effects in shovel design. Applied Ergonomics 21, 39-42.

Kelsey, Jennifer L., et al., 1984. An Epidemiologic Study of Lifting and Twisting on the Job and Risk for Acute Prolapsed Lumbar Intervertebral Disc. Journal of Orthopaedic Research 2, 61-66.

Marras, W.S., Lavender, S.A., Leurgans, S.E., Fathallah, F.A., Ferguson, S.A., Allread, W.G., and Rajulu, S.L., 1995. Biomechanical risk factors for occupationally related low back disorders. Ergonomics 38, 377-410.

McGorry, R.W., Dempsey, P.G., Leamon, T.B., 2003. The effect of technique and shaft configuration in snow shoveling on physiologic, kinematic, kinetic, and productivity variables. Applied Ergonomics 34, 225-231.

Punnett, L., Fine, L.J., Keyersling, W.M., Herrin, G.D, Chaffin, D.B, 1991. Back disorders and nonneutral trunk postures of automobile assembly workers. Scandavian Journal of Work, Environment, and Health 17, 337-346.

APPENDIX A

FLYER TO RECRUIT SUBJECTS

INTERESTED IN EARNING A $20 **TARGET** GIFT CARD??

We are looking for participants for research in ergonomics studying the effects of using two new handle configurations when raking and shoveling.

Participants must be between the ages of 18 and 40 years old and must not have any health problems or back problems. In this study you will be asked to perform raking and shoveling tasks while hooked up to motion measurement sensors. The study will take 1-2 hours.

If you are interested in participating, please email mcauley.12@osu.edu.

ERGONOMICS RESEARCH mcauley.12@osu.edu ERGONOMICS RESEARCH mcauley.12@osu.edu ERGONOMICS RESEARCH mcauley.12@osu.edu ERGONOMICS RESEARCH mcauley.12@osu.edu ERGONOMICS RESEARCH mcauley.12@osu.edu ERGONOMICS RESEARCH mcauley.12@osu.edu ERGONOMICS RESEARCH mcauley.12@osu.edu ERGONOMICS RESEARCH mcauley.12@osu.edu ERGONOMICS RESEARCH mcauley.12@osu.edu ERGONOMICS RESEARCH mcauley.12@osu.edu

APPENDIX B

INFORMED CONSENT DOCUMENT

The Ohio State University Consent to Participate in Research

Study Title: ERGONOMIC EVALUATION OF TWO ALTERNATIVE HANDLES FOR SHOVELS AND RAKES DESIGNED TO PREVENT LOW BACK PAIN

Principal Investigator: Steven Lavender, Ph.D.

Sponsor: OSU Internal Support

- **This is a consent form for research participation.** It contains important information about this study and what to expect if you decide to participate. Please consider the information carefully. Feel free to discuss the study with your friends and family and to ask questions before making your decision whether or not to participate.
- **Your participation is voluntary.** You may refuse to participate in this study. If you decide to take part in the study, you may leave the study at any time. No matter what decision you make, there will be no penalty to you and you will not lose any of your usual benefits. Your decision will not affect your future relationship with The Ohio State University. If you are a student or employee at Ohio State, your decision will not affect your grades or employment status.
- **You may or may not benefit as a result of participating in this study.** Also, as explained below, your participation may result in unintended or harmful effects for you that may be minor or may be serious depending on the nature of the research.
- **You will be provided with any new information that develops during the study that may affect your decision whether or not to continue to participate.** If you decide to participate, you will be asked to sign this form and will receive a copy of the signed form. You are being asked to consider participating in this study for the reasons explained below.

1. **Why is this study being done?**
   This study is to determine if using an alternative handle will decrease low back pain when raking and shoveling.

2. **How many people will take part in this study?**
   There will be 14 subjects.

3. **What will happen if I take part in this study?**
   If you choose to participate in this study, you will both rake and shovel with and without two alternative handles. The order of either raking or shoveling is randomized. Therefore, if you do raking first, you will rake with both alternative handles and without one (the handle conditions will also be in random order), and then you will shovel with both handles and without (the handle conditions will also be in random order). This order will be reversed if

you shovel first. For each handle condition, you will perform the motion eight times in succession twice. The first set of eight will be a practice so that you will be comfortable performing the task. The second set will be used to collect data. Between the first and second set, there will be a one-minute break. Between each handle condition, there will be a one-minute break, and between raking and shoveling, there will be a five-minute break.

4. How long will I be in the study?
The study will take between 1-2 hours.

5. Can I stop being in the study?

You may leave the study at any time. If you decide to stop participating in the study, there will be no penalty to you, and you will not lose any benefits to which you are otherwise entitled. Your decision will not affect your future relationship with The Ohio State University.

6. What risks, side effects or discomforts can I expect from being in the study?

There is a small chance that you may have some minor discomfort. After the study you may experience some muscle soreness for a few days if you are not used to shoveling or raking. If you feel any discomfort during the study, please let the investigator know, and the study will be stopped immediately.

7. What benefits can I expect from being in the study?

There are no direct benefits for those participating

8. What other choices do I have if I do not take part in the study?

You may choose not to participate without penalty or loss of benefits to which you are otherwise entitled.

9. Will my study-related information be kept confidential?

Efforts will be made to keep your study-related information confidential. However, there may be circumstances where this information must be released. For example, personal information regarding your participation in this study may be disclosed if required by state law. Also, your records may be reviewed by the following groups (as applicable to the research):

- Office for Human Research Protections or other federal, state, or international regulatory agencies;
- U.S. Food and Drug Administration;
- The Ohio State University Institutional Review Board or Office of Responsible Research Practices;

If the study involves the use of your protected health information, you may also be asked to sign a separate Health Insurance Portability and Accountability Act (HIPAA) research authorization form.

10. What are the costs of taking part in this study?

There are no costs involved with taking part in the study.

11. Will I be paid for taking part in this study?

You will receive a $20 gift card to Target for participating.

12. What happens if I am injured because I took part in this study?

If you suffer an injury from participating in this study, you should notify the researcher or study doctor immediately, who will determine if you should obtain medical treatment at The Ohio State University Medical Center.

The cost for this treatment will be billed to you or your medical or hospital insurance. The Ohio State University has no funds set aside for the payment of health care expenses for this study.

13. What are my rights if I take part in this study?

If you choose to participate in the study, you may discontinue participation at any time without penalty or loss of benefits. By signing this form, you do not give up any personal legal rights you may have as a participant in this study.

You may refuse to participate in this study without penalty or loss of benefits to which you are otherwise entitled.

An Institutional Review Board responsible for human subjects research at The Ohio State University reviewed this research project and found it to be acceptable, according to applicable state and federal regulations and University policies designed to protect the rights and welfare of participants in research.

14. Who can answer my questions about the study?

For questions, concerns, or complaints about the study you may contact **Kelly McAuley (mcauley.12@osu.edu)**.

For questions about your rights as a participant in this study or to discuss other study-related concerns or complaints with someone who is not part of the research team, you

may contact Ms. Sandra Meadows in the Office of Responsible Research Practices at 1-800-678-6251.

If you are injured as a result of participating in this study or for questions about a study-related injury, you may contact **Dr. Steven Lavender 292-9980**.

15. Signing the consent form

I have read (or someone has read to me) this form and I am aware that I am being asked to participate in a research study. I have had the opportunity to ask questions and have had them answered to my satisfaction. I voluntarily agree to participate in this study.

I am not giving up any legal rights by signing this form. I will be given a copy of this signed form.

Printed name of subject	Signature of subject
	MM/DD/YYYY
	Date and time
Printed name of person authorized to consent for subject (when applicable)	Signature of person authorized to consent for subject (when applicable)
	MM/DD/YYYY
Relationship to the subject	Date and time

Investigator/Research Staff

I have explained the research to the participant or his/her representative before requesting the signature(s) above. There are no blanks in this document. A signed copy of this form has been given to the participant or his/her representative.

Printed name of person obtaining consent	Signature of person obtaining consent
	MM/DD/YYYY
	Date and time

Witness(es) - *May be left blank if not required by the IRB*

Printed name of witness	Signature of witness
	MM/DD/YYYY
	Date and time
Printed name of witness	Signature of witness
	MM/DD/YYYY
	Date and time

APPENDIX C

SAMPLE DATA COLLECTION FORM

Subject XX

Name: _____

Subject ID: _____

Weight: _____

Age: _____

Height: _____

Shoulder Height: _____

Elbow Height: _____

Index Finger Height: _____

Hip Width: _____

Knee Width: _____

Ankle Breadth: _____

Shoulder Relocate: _____

Shoveling

BackSaver Grip
No Handle
BackSaving Handle

Raking

No Handle
BackSaver Grip
BackSaving Handle

APPENDIX D

SAS SOFTWARE CODE FOR SHOVELING

```
**OPTIONS LINESIZE=72;
DATA DATA1;
        INPUT SUBJECT$ TRIAL$ TOOL$ HANDLE$ FLEX LAT TWIST
FLEXMOM LATMOM TWISTMOM;
        *** code the treatment combinations 01111,01112,...14523;
        TC = trim(SUBJECT)||trim(TRIAL)||trim(TOOL)||trim(HANDLE);
        Drop tool;
LINES;
```

1	1	0	0	44.31	19.01	26.63	57.44	91.60	35.92
1	2	0	0	43.87	24.24	28.28	74.59	102.07	29.89
1	3	0	0	42.10	20.56	25.97	75.35	87.77	37.03
1	4	0	0	41.32	27.20	31.60	77.19	96.08	29.32
1	5	0	0	44.78	23.18	27.45	82.20	84.32	33.20
1	1	0	1	34.38	17.31	27.42	76.07	98.92	32.74
1	2	0	1	38.90	15.86	19.38	78.40	105.46	26.12
1	3	0	1	34.19	21.27	22.08	81.21	92.64	38.35
1	4	0	1	37.67	16.60	21.89	96.04	99.64	36.96
1	5	0	1	36.79	15.78	23.91	83.66	96.14	31.38
1	1	0	2	38.95	21.33	22.57	97.61	99.14	28.15
1	2	0	2	37.09	16.54	25.69	83.51	82.46	29.75
1	3	0	2	38.51	14.89	20.76	75.21	88.00	23.91
1	4	0	2	35.46	9.52	22.02	75.51	93.05	25.37
1	5	0	2	36.34	15.42	23.69	89.03	94.44	25.58
2	1	0	0	24.14	12.74	36.40	51.31	227.87	82.11
2	2	0	0	30.22	14.53	32.16	69.53	235.91	82.74
2	3	0	0	28.79	12.76	29.63	78.13	234.27	72.27
2	4	0	0	27.80	17.02	32.19	107.46	207.06	81.85
2	5	0	0	27.74	16.06	28.76	111.35	227.03	87.19
2	1	0	1	20.59	14.40	28.73	100.96	165.53	44.43
2	2	0	1	22.03	9.23	26.25	106.12	156.50	43.17
2	3	0	1	23.09	10.26	26.50	65.41	151.16	45.51
2	4	0	1	33.45	19.98	23.42	77.93	134.43	41.74
2	5	0	1	19.96	13.13	26.83	58.82	180.68	74.56
2	1	0	2	51.84	15.37	30.20	94.59	126.04	16.64
2	2	0	2	11.66	14.95	25.56	38.77	161.21	68.19
2	3	0	2	14.48	16.66	28.86	39.73	145.38	55.92
2	4	0	2	6.45	20.71	32.55	45.76	140.63	51.60
2	5	0	2	32.12	18.80	25.22	70.92	129.23	30.36
3	1	0	0	70.88	25.06	32.52	88.34	204.78	36.87
3	2	0	0	71.60	21.72	32.57	63.44	203.65	55.44
3	3	0	0	70.66	22.40	33.69	74.31	185.07	41.40
3	4	0	0	72.77	18.95	27.44	70.18	172.97	31.00

3	5	0	0	68.85	21.51	28.16	93.65	195.42	35.50
3	1	0	1	55.19	21.40	30.28	83.58	151.27	13.42
3	2	0	1	56.51	18.01	33.24	83.31	156.17	17.92
3	3	0	1	55.46	22.43	28.32	106.20	141.45	21.26
3	4	0	1	56.75	23.58	28.24	82.88	146.90	21.63
3	5	0	1	64.64	20.76	26.22	100.15	178.90	22.21
3	1	0	2	65.06	21.56	30.65	82.58	165.14	16.15
3	2	0	2	62.69	23.82	24.67	78.36	169.53	23.20
3	3	0	2	54.26	21.05	28.07	101.18	170.82	21.42
3	4	0	2	66.67	23.67	27.68	105.01	198.76	16.11
3	5	0	2	65.25	22.40	25.61	98.44	182.02	13.53
4	1	0	0	62.04	30.77	20.66	118.51	230.76	80.25
4	2	0	0	64.12	37.06	20.18	116.35	260.24	59.33
4	3	0	0	61.91	27.12	18.39	141.28	250.37	87.33
4	4	0	0	64.24	36.96	20.30	109.15	292.69	92.50
4	5	0	0	66.79	35.90	22.94	104.01	275.28	78.42
4	1	0	1	65.76	28.96	19.10	130.39	241.66	48.70
4	2	0	1	64.91	25.59	20.25	99.73	206.85	38.16
4	3	0	1	57.69	24.70	25.11	105.49	214.34	48.46
4	4	0	1	56.09	23.50	20.71	100.30	211.07	54.99
4	5	0	1	55.13	29.65	16.29	117.55	194.34	52.96
4	1	0	2	64.05	24.50	13.50	135.35	202.38	52.72
4	2	0	2	52.75	24.70	14.74	125.12	228.59	48.26
4	3	0	2	61.08	23.89	18.35	125.91	190.85	68.87
4	4	0	2	56.25	22.33	15.63	118.23	203.79	48.59
4	5	0	2	60.79	24.13	29.68	88.79	211.25	43.60
5	1	0	0	57.39	16.99	32.14	73.13	102.79	46.65
5	2	0	0	65.50	17.90	27.06	84.27	96.53	50.68
5	3	0	0	63.71	20.37	22.88	89.25	102.28	50.06
5	4	0	0	62.43	21.44	27.04	74.01	121.46	47.54
5	5	0	0	65.01	13.70	26.80	97.85	115.10	51.24
5	1	0	1	56.15	23.39	35.16	63.65	100.20	28.60
5	2	0	1	62.00	31.35	34.71	57.25	106.55	27.48
5	3	0	1	57.03	24.08	37.84	80.10	108.81	19.20
5	4	0	1	57.49	29.63	37.82	58.06	94.26	26.89
5	5	0	1	54.32	20.46	35.26	81.78	88.03	26.31
5	1	0	2	61.59	22.71	30.94	50.61	101.07	25.51
5	2	0	2	61.69	14.90	27.71	69.47	95.79	21.60
5	3	0	2	60.96	24.44	28.76	77.70	97.05	24.54
5	4	0	2	61.34	19.37	24.80	58.71	79.42	22.98
5	5	0	2	61.52	24.64	30.87	73.75	91.88	19.67
6	1	0	0	40.65	25.34	30.86	107.51	115.71	116.62
6	2	0	0	42.17	16.22	31.50	101.37	133.90	107.27
6	3	0	0	20.96	13.43	21.08	86.36	143.54	102.57
6	4	0	0	20.97	13.75	20.89	106.75	139.03	124.18

6	5	0	0	22.30	16.56	22.53	96.67	141.79	101.60
6	1	0	1	37.70	26.16	23.76	101.11	246.11	109.89
6	2	0	1	38.80	21.92	23.76	107.66	177.64	105.17
6	3	0	1	41.15	19.81	23.16	104.71	142.89	109.29
6	4	0	1	60.40	37.45	15.36	68.66	370.09	67.84
6	5	0	1	59.45	43.60	18.56	107.65	353.36	45.16
6	1	0	2	35.46	14.47	18.69	121.78	161.35	97.76
6	2	0	2	37.17	18.82	20.30	128.02	152.74	100.83
6	3	0	2	38.83	18.17	22.12	120.22	149.21	106.57
6	4	0	2	36.20	19.15	19.46	118.14	154.64	124.88
6	5	0	2	35.25	12.71	19.09	111.46	139.43	116.70
7	1	0	0	50.73	20.34	26.72	80.47	220.26	119.95
7	2	0	0	49.81	19.69	25.59	233.27	227.04	122.35
7	3	0	0	48.54	20.76	28.04	68.99	199.12	122.03
7	4	0	0	49.73	20.72	27.56	88.40	189.06	123.23
7	5	0	0	49.43	16.89	26.51	80.54	216.27	124.58
7	1	0	1	45.76	20.48	32.04	112.18	242.61	53.83
7	2	0	1	49.27	23.45	30.93	99.87	242.12	101.69
7	3	0	1	51.51	23.36	27.29	116.21	253.88	67.83
7	4	0	1	50.81	30.61	26.77	155.05	264.44	101.34
7	5	0	1	47.87	25.61	28.74	101.44	225.04	93.64
7	1	0	2	45.30	23.27	18.60	86.01	225.40	90.52
7	2	0	2	45.79	22.52	22.52	84.94	224.21	99.91
7	3	0	2	44.47	27.64	27.11	93.28	218.07	93.24
7	4	0	2	49.64	24.86	22.40	84.15	240.60	99.17
7	5	0	2	45.74	24.30	26.79	85.50	213.10	111.60
8	1	0	0	42.28	13.82	28.70	57.58	93.38	25.93
8	2	0	0	40.91	17.93	26.47	62.04	91.99	27.22
8	3	0	0	44.15	14.80	22.01	61.85	102.84	27.00
8	4	0	0	41.44	18.84	24.16	91.03	91.02	28.48
8	5	0	0	43.06	14.45	26.33	82.37	92.82	31.90
8	1	0	1	43.35	17.46	16.69	109.00	106.37	37.47
8	2	0	1	31.79	10.75	19.56	94.45	105.04	42.34
8	3	0	1	29.25	13.91	16.87	70.78	98.41	28.80
8	4	0	1	28.45	14.42	10.09	62.22	89.08	39.88
8	5	0	1	32.28	14.42	12.78	75.69	103.94	27.49
8	1	0	2	29.72	10.54	12.34	69.56	98.41	29.13
8	2	0	2	31.66	15.78	19.23	89.75	87.19	23.01
8	3	0	2	35.03	11.84	18.42	74.99	108.90	25.37
8	4	0	2	32.01	13.38	18.48	78.70	102.12	20.94
8	5	0	2	34.98	14.80	18.94	75.51	97.57	35.16
9	1	0	0	45.47	23.03	31.27	90.55	103.68	30.14
9	2	0	0	43.23	10.32	32.89	65.80	99.72	32.73
9	3	0	0	53.19	15.77	27.82	61.97	80.91	34.02
9	4	0	0	55.06	16.07	28.34	70.26	86.04	19.32

9	5	0	0	51.29	18.92	33.91	86.41	118.96	30.02
9	1	0	1	39.95	11.70	23.67	64.32	80.89	21.09
9	2	0	1	39.17	12.83	24.84	86.06	83.27	30.76
9	3	0	1	43.32	8.59	24.28	77.43	85.12	24.18
9	4	0	1	42.01	7.73	22.77	76.09	84.05	25.45
9	5	0	1	41.93	6.01	24.45	71.99	85.02	29.03
9	1	0	2	44.39	10.65	26.11	69.31	88.76	30.43
9	2	0	2	44.79	11.84	20.98	69.94	92.33	27.05
9	3	0	2	40.03	10.84	19.72	67.73	86.54	30.10
9	4	0	2	41.68	9.44	24.68	64.28	87.93	26.52
9	5	0	2	39.92	7.51	22.54	61.77	77.67	27.17
10	1	0	0	52.96	17.03	29.67	124.40	148.71	33.62
10	2	0	0	59.34	25.30	31.92	119.40	155.42	41.74
10	3	0	0	55.99	29.82	27.72	123.28	152.70	32.71
10	4	0	0	56.28	33.88	27.74	125.83	153.41	42.23
10	5	0	0	49.98	37.06	37.65	102.85	123.55	33.22
10	1	0	1	48.58	20.24	27.67	86.94	139.69	26.52
10	2	0	1	52.91	22.23	23.89	94.74	137.50	27.21
10	3	0	1	51.87	23.47	24.45	106.69	137.86	28.39
10	4	0	1	49.87	17.36	29.65	99.35	132.63	29.52
10	5	0	1	54.60	23.25	25.04	104.13	130.32	31.12
10	1	0	2	51.35	30.76	23.09	90.01	116.54	21.57
10	2	0	2	51.10	24.15	26.66	113.60	122.36	19.94
10	3	0	2	51.06	29.11	23.41	145.24	114.44	26.82
10	4	0	2	52.10	28.08	25.74	120.47	106.01	16.85
10	5	0	2	47.91	26.71	30.52	116.80	118.24	28.24
11	1	0	0	78.95	34.73	24.43	105.39	185.41	28.29
11	2	0	0	82.16	60.17	30.81	91.70	185.62	23.54
11	3	0	0	63.70	43.33	23.04	82.17	143.07	24.49
11	4	0	0	84.42	60.52	31.15	100.11	204.06	30.98
11	5	0	0	81.33	65.68	34.95	96.67	190.88	28.31
11	1	0	1	60.90	43.56	29.37	78.73	160.00	20.79
11	2	0	1	58.88	37.75	28.08	81.99	174.54	34.41
11	3	0	1	61.63	35.51	24.56	75.23	157.61	23.55
11	4	0	1	53.58	27.54	24.59	79.78	130.54	24.14
11	5	0	1	58.20	35.74	21.12	95.48	157.32	27.70
11	1	0	2	61.44	38.68	25.60	85.82	163.91	33.25
11	2	0	2	62.99	35.11	22.77	92.10	135.68	26.29
11	3	0	2	53.29	21.98	24.60	143.36	115.07	33.07
11	4	0	2	58.94	34.86	21.63	84.46	151.16	29.93
11	5	0	2	47.42	22.63	21.26	92.55	139.68	19.27
12	1	0	0	70.53	30.64	33.82	71.99	161.77	26.94
12	2	0	0	67.09	34.44	31.43	81.86	162.71	30.77
12	3	0	0	65.14	31.70	31.55	82.26	176.11	29.42
12	4	0	0	67.91	24.82	31.63	67.84	151.97	17.22

```
12  5  0  0  65.09  30.84  35.83  81.99  179.36  21.27
12  1  0  1  58.65  31.00  18.56  113.38  162.74  26.56
12  2  0  1  48.54  28.08  20.51  93.11  174.48  25.87
12  3  0  1  44.09  35.75  30.42  110.59  161.61  29.62
12  4  0  1  54.92  31.86  25.11  83.97  149.19  27.73
12  5  0  1  50.29  38.22  24.97  103.52  154.17  29.93
12  1  0  2  63.44  38.64  30.78  93.72  156.40  18.27
12  2  0  2  48.99  34.52  25.96  94.35  143.50  24.70
12  3  0  2  41.91  36.01  24.16  91.49  146.22  36.39
12  4  0  2  50.69  32.17  28.34  114.53  137.96  28.35
12  5  0  2  43.88  36.13  34.89  115.51  130.85  31.34
13  1  0  0  43.11  16.59  25.79  46.04  178.61  38.95
13  2  0  0  41.08  10.70  26.59  50.44  185.76  23.21
13  3  0  0  39.03  18.06  24.14  59.64  178.41  31.29
13  4  0  0  42.58  14.96  26.74  47.65  179.25  29.11
13  5  0  0  42.70  14.00  25.84  49.30  198.96  30.48
13  1  0  1  46.51  24.51  17.10  118.14  185.01  26.15
13  2  0  1  34.86  9.97  21.56  62.68  183.68  31.49
13  3  0  1  38.93  6.82  22.09  57.78  163.42  27.94
13  4  0  1  40.41  10.26  22.96  74.21  154.71  22.49
13  5  0  1  38.34  9.46  26.27  59.54  166.44  32.40
13  1  0  2  36.67  10.27  22.25  38.57  175.67  34.58
13  2  0  2  38.60  13.39  21.48  41.40  170.15  33.55
13  3  0  2  38.03  10.69  21.68  54.90  161.51  28.94
13  4  0  2  35.81  10.68  22.58  49.99  161.60  34.96
13  5  0  2  36.09  10.68  25.93  53.71  168.50  36.29
14  1  0  0  34.17  21.39  33.29  65.45  162.14  49.41
14  2  0  0  38.49  22.23  25.85  81.32  168.81  43.61
14  3  0  0  28.64  9.62  27.43  71.62  164.65  51.89
14  4  0  0  31.85  15.95  28.75  87.04  161.69  33.20
14  5  0  0  33.85  20.51  26.71  84.90  163.46  49.88
14  1  0  1  35.04  25.92  27.09  65.12  171.17  36.78
14  2  0  1  32.92  29.03  28.21  60.23  165.30  42.21
14  3  0  1  35.68  23.61  30.21  53.73  152.75  33.89
14  4  0  1  37.96  26.18  22.85  58.33  167.50  43.68
14  5  0  1  36.91  28.57  24.22  49.37  150.46  38.24
14  1  0  2  30.72  19.13  19.31  69.15  164.07  39.35
14  2  0  2  34.60  13.14  24.02  54.93  163.39  24.98
14  3  0  2  38.99  18.33  28.34  54.44  151.09  35.65
14  4  0  2  33.78  25.07  33.64  69.29  159.04  43.32
14  5  0  2  35.26  21.01  26.33  65.95  165.76  41.88


;
proc sort;
```

```
        by subject handle trial;
run;
proc means noprint;
        var flex lat twist flexmom latmom twistmom;
        by subject handle;
        output out=avgtrial mean=mflex mlat mtwist mflexmom mlatmom mtwistmom;
        run;

proc glm;
        class subject handle;
        model mflex mlat mtwist mflexmom mlatmom mtwistmom = subject handle;
        means handle/regwq;
        title 'analysis of shovel handle conditions';
        run;

proc sort;
        by handle;
        run;

proc means n mean std stderr min max;
        by handle;
        run;
```

APPENDIX E

SAS SOFTWARE CODE FOR RAKING

```
**OPTIONS LINESIZE=72;
DATA DATA1;
        INPUT SUBJECT$ TRIAL$ TOOL$ HANDLE$ FLEX LAT TWIST
FLEXMOM LATMOM TWISTMOM;
        *** code the treatment combinations 01111,01112,...14523;
        TC = trim(SUBJECT)||trim(TRIAL)||trim(TOOL)||trim(HANDLE);
        Drop tool;
        LINES;

2       1       1       0       16.69   19.75   7.01    56.40   73.32   44.78
2       2       1       0       21.66   21.60   7.34    53.54   71.82   46.86
2       3       1       0       24.05   21.44   6.25    58.41   73.08   44.14
2       4       1       0       27.55   21.78   6.63    66.18   76.04   45.09
2       5       1       0       25.86   19.12   6.78    65.47   76.82   41.37
2       1       1       1       7.71    20.62   7.91    52.01   74.94   37.47
2       2       1       1       11.36   20.08   8.06    62.65   74.92   44.08
2       3       1       1       11.48   18.31   6.17    62.94   70.73   36.53
2       4       1       1       11.03   19.40   7.06    60.67   76.94   34.73
2       5       1       1       10.21   19.19   8.19    61.72   82.88   37.03
2       1       1       2       9.02    21.73   7.48    64.85   59.61   32.41
2       2       1       2       6.96    22.42   8.54    55.07   58.61   30.25
2       3       1       2       8.45    19.62   9.27    60.25   55.55   31.91
2       4       1       2       12.57   17.64   6.05    68.09   57.01   28.49
2       5       1       2       6.95    21.03   8.52    62.96   56.66   28.73
3       1       1       0       56.81   29.74   8.80    92.18   130.88  14.46
3       2       1       0       59.54   33.57   8.90    94.27   145.27  21.18
3       3       1       0       59.62   32.27   6.05    96.98   146.36  13.80
3       4       1       0       56.80   28.68   6.62    95.56   141.70  11.51
3       5       1       0       55.73   28.86   7.41    84.79   117.47  19.44
3       1       1       1       41.21   21.43   10.43   93.25   99.73   11.13
3       2       1       1       40.47   20.93   11.75   91.46   96.70   9.78
3       3       1       1       38.40   19.60   12.45   85.67   98.24   12.69
3       4       1       1       41.91   18.61   10.26   88.75   101.75  7.52
3       5       1       1       43.26   19.82   17.20   78.64   88.19   9.37
3       1       1       2       41.34   22.72   9.87    77.39   87.05   12.02
3       2       1       2       36.35   23.54   10.36   83.96   83.48   11.11
3       3       1       2       35.53   25.13   11.04   91.72   99.23   16.33
3       4       1       2       38.66   23.07   12.59   84.32   96.16   13.77
3       5       1       2       37.89   23.59   13.18   73.22   82.96   12.18
6       1       1       0       29.10   15.13   4.30    69.42   103.17  27.12
6       2       1       0       28.73   17.08   5.41    80.37   105.85  26.65
6       3       1       0       30.69   16.60   5.29    78.75   106.98  32.19
6       4       1       0       31.08   20.09   4.63    84.81   107.16  39.66
6       5       1       0       33.64   20.28   3.97    82.16   162.64  40.69
6       1       1       1       19.59   7.20    9.24    54.69   77.53   28.03
```

```
6	2	1	1	20.06	6.64	10.79	48.91	85.70	27.42
6	3	1	1	20.08	7.80	10.92	58.81	83.33	33.72
6	4	1	1	21.79	5.79	10.45	68.53	75.40	39.39
6	5	1	1	21.95	80.42	11.21	53.47	73.71	27.82
6	1	1	2	22.03	8.35	4.95	44.26	84.50	17.83
6	2	1	2	22.70	9.55	7.17	44.11	86.56	17.73
6	3	1	2	22.28	8.52	5.59	45.25	94.55	17.83
6	4	1	2	21.41	8.38	7.37	43.65	89.07	17.62
6	5	1	2	22.31	11.84	11.04	49.98	97.00	16.85
7	1	1	0	41.47	30.67	5.41	34.29	84.18	55.19
7	2	1	0	42.21	31.28	6.18	47.15	89.59	50.35
7	3	1	0	43.88	31.17	7.41	38.25	84.79	51.82
7	4	1	0	42.88	29.10	7.74	35.32	86.93	50.01
7	5	1	0	41.99	28.73	6.93	37.34	88.12	45.71
7	1	1	1	32.12	20.64	4.84	54.15	68.27	39.93
7	2	1	1	32.41	20.52	4.98	56.57	68.85	37.66
7	3	1	1	32.06	20.01	5.64	49.52	68.14	38.84
7	4	1	1	31.49	19.97	2.96	50.43	67.76	38.56
7	5	1	1	31.00	20.53	4.77	60.02	66.73	44.91
7	1	1	2	38.34	25.92	10.70	57.18	87.30	48.73
7	2	1	2	35.71	26.13	9.93	59.79	85.00	49.76
7	3	1	2	38.35	26.69	12.18	63.86	84.35	48.21
7	4	1	2	35.38	27.81	10.95	65.50	86.19	46.46
7	5	1	2	39.03	27.16	7.31	55.13	78.55	46.62
```

```
;
proc sort;
	by subject handle trial;
run;
proc means noprint;
	var flex lat twist flexmom latmom twistmom;
	by subject handle;
	output out=avgtrial mean=mflex mlat mtwist mflexmom mlatmom mtwistmom;
	run;

proc glm;
	class subject handle;
	model mflex mlat mtwist mflexmom mlatmom mtwistmom = subject handle;
	means handle/regwq;
	title 'analysis of rake handle conditions';
	run;

proc sort;
```

```
        by handle;
        run;

proc means n mean std stderr min max;
        by handle;
        run;
```